NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2394

EFFECTS OF DESIGN DETAILS ON THE FATIGUE STRENGTH OF 355-T6 SAND-CAST ALUMINUM ALLOY

By M. Holt and I. D. Eaton

Aluminum Company of America

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SUMMARY

Static and fatigue tests were made on 355-T6 sand-cast plate-type aluminum-alloy specimens incorporating holes, bosses, and ribs.

In the static tests the tensile strength of the plain plate-type specimen agreed within 3 percent with the strength of separately cast test bars. In terms of the average stress on the minimum net section of one specimen of each type, all the design details studied reduced the static strengths of the plate-type specimens. The reductions ranged from 4650 to 9000 psi or 13 to 26 percent.

Of the design details studied, the unreinforced hole was the most effective stress-raiser for fatigue lives from 10,000 to 25,000,000 cycles. The unreinforced hole in the sand-cast specimen was not so severe in reducing the fatigue strength as a similar hole in wrought 17S-T4, 27S-T6, 53S-T6, or 14S-T6 plate.

The fractures of both the static and fatigue specimens with a boss or rib were generally in cross sections close to the edge of the boss or rib.

INTRODUCTION

The effects of surface conditions, internal porosity, blow holes, dross inclusions, and so forth on the fatigue strength of aluminum-alloy sand castings have been investigated at the Aluminum Research Laboratories of the Aluminum Company of America using plate-type specimens of 355-T6 alloy. (See reference 1.) In a comparison of results of tests of specimens containing the above defects with results of tests of similar specimens containing no intentional defects, it was found that the defects studied did not cause losses of strength in proportion to their supposed importance. The specimens containing excessive porosity had fatigue strengths within 10 percent of the average for normally sound specimens.

In addition to the foregoing investigation a similar investigation has been made of the effects of design details on the fatigue strength of 355-T6 sand-cast aluminum alloy using the same general type of specimen. After consideration of the types of design details encountered in practice several types were selected for this investigation as follows: Unreinforced holes, bosses with and without holes, and ribs. The effect of changing fillet radii on bosses was included.

The object of this investigation was to study the effects of design details such as open holes and reinforcements upon the static and fatigue strengths of 355-T6 aluminum-alloy sand-cast specimens. The reinforcements include bosses, with and without holes, and ribs. A comparison will be made of the effects of these design details with the effects of normal casting defects.

This work was done by the Aluminum Company of America and has been made available to the NACA for publication because of its general interest.

MATERIAL AND SPECIMENS

All of the specimens used in this investigation were cast in Cleveland in accordance with a design suggested by Mr. R. L. Templin. The castings were prepared for test in the Machine Shop of the Aluminum Research Laboratories, New Kensington, Pennsylvania. The mechanical properties shown in table I were determined at Cleveland on separately cast test bars. The properties are, in general, quite uniform and in agreement with Federal Specification QQ-A-601, Class 10. The specimens were radiographed in Cleveland, and only those found to be generally sound were submitted for test, thereby eliminating a possible source of variation in the specimens.

Certain design details were studied by modifying a basic plate-type pattern $8\frac{1}{4}$ inches wide as indicated in figure 1. Modifications were made by adding bosses with fillets of rather short and rather long radii, by adding ribs, and in certain specimens by drilling holes. In the test section, the thickness varied uniformly to a minimum of 1/4 inch at the center. The section of minimum cross-sectional area was therefore not at the center of the various types of specimens with bosses and ribs.

A finished test specimen of the plain type is shown in figure 2. The thickened ends were finished by machining and a light machining cut was taken on the edges. The faces of the test section were left with as-cast surface. In the case of specimens with bosses and ribs, the tops of the projections were machined flat and parallel to the axis of the specimen. The specimens of type 1 were cast with a 1/8-inch-high boss on each face. This boss was machined off even with the surrounding surface and then a hole was drilled in the center of the machined area and reamed to 1-inch diameter. Thus the rim of the hole had machined surfaces. The specimens of types 2A and 3A were simply types 2 and 3, respectively, with a hole drilled at the center of the boss and reamed to 1-inch diameter.

PROCEDURE

Both static and fatigue tests were made on specimens of the types shown in figure 1.

The static tests were made in an Amsler Universal testing machine[1] of the hydraulic type having a maximum capacity of 300,000 pounds. The test setup is shown in figure 3. A strain survey was made on the plain-type specimen to check the uniformity of stress across the section. SR-4 type A-1 electric-resistance wire strain gages were mounted near each edge and at the center of each face of the specimen. The six values of measured strain were within 8 percent of the average value. The distribution of stress across the specimen was quite uniform but there was some bending of the specimen normal to the plane of the plate.

The majority of the fatigue tests were made in units 7 and 8 of the Aluminum Research Laboratories Structural Fatigue Testing Machines shown in the foreground of figure 4 and in the close-up of figure 5 (reference 2). With the adapters shown in figure 5 the capacity of these machines is 40,000 pounds. The desired test conditions for these tests were obtained by: (1) Adjustment of the crank displacement at the end of the loading beam to obtain the desired load range and (2) adjustment of the turnbuckle at the crank end of the loading beam to position the desired range from zero to a maximum in tension (stress ratio equal to zero). The specimen was subjected to the desired test conditions for approximately 3000 cycles, readjusted to the desired conditions if necessary, and the test was continued until the specimen had failed or had completed 25,000,000 or more cycles of stress without failure. When failure occurred the machine was stopped by an automatic cut-off switch which has been found sufficiently sensitive that a change in load of less than 600 pounds will stop the machine. The number of cycles of loading was determined by a cycle counter which indicated each 100 cycles of machine operation.

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[1]Type 150, SZBDA Serial No. 5254. Periodic calibration of this machine indicates that the error in load reading is less than 1 percent throughout the range.

A stress survey on a plain-type specimen using Huggenberger Tensometers indicated that variation of stress over the central section was not more than 6 percent from the average under fatigue loading conditions. Apparently a small amount of bending is present in spite of the fact that the auxiliary plate fulcra on the adapters are carefully alined with the axis of the specimen.

A few specimens were fatigue-tested at loads greater than 40,000 pounds in the Amsler Universal Testing Machine using the fixtures previously described for the static tests. The specimens were subjected to a stress cycle from zero to a maximum in tension by the operator of the machine. In view of the time consumed in testing the specimens in this manner, the tests were discontinued when the specimen had either failed or withstood approximately 1000 cycles of stress without failure.

RESULTS

The tensile properties of the castings as determined by the tests on the separately cast test bars are given in table I. Although the specimens were not all made at the same time, the tensile strengths agree very well. The tensile properties conform to the requirements of Federal Specification QQ-A-601, Class 10, and, in general agree with the following typical values (table 21, reference 3):

Tensile strength, psi	35,000
Yield strength (offset, 0.2-percent), psi	25,000
Elongation in 2 inches, percent	3.0

The static tensile strengths of the cast plate-type specimens are given in table II. These strengths are based on the net area of a rectangular cross section which, in the case of types 2 to 6 inclusive, was taken at the edge of the boss or rib. As seen in the illustration of static fractures, figure 6, the specimens with a boss or rib failed approximately at this section. It will be seen that the strengths of the plain-type cast specimen and the separately cast test bars agree within about 3 percent. Stress-concentration factors, as represented by the ratios of the static strengths of the separately cast test bars to those of the plate-type specimens with bosses and ribs, range as high as 1.30.

The results of the individual fatigue tests are given in table III and figure 7. The results of all the tests are plotted in figure 7(a). It is evident that the scatter of results in the tests for the plain-type, type 3A, and type 5 specimens approaches or equals in magnitude the differences in fatigue strengths between specimen types. Therefore, there is indicated on this plot a band of scatter which appears to be inherent within the material.

The results of tests on plain-type and type 1 specimens are superimposed on the scatter bands in figure 7(b). It is evident from the curves that, with the exception of the static point, these types determine the limits of the scatter band obtained in this investigation. The effects of the hole in reducing the fatigue strength can be seen from the following tabulation, the ratio being considered the fatigue strength reduction factor.

Specimen type	Fatigue strength (psi) and fatigue strength reduction factor at -		
	10^5 cycles	2×10^6 cycles	10^7 cycles
Plain	18,500	8,900	7,650
Type 1	13,650	6,900	5,600
Ratio = $\frac{\text{Plain}}{\text{Type 1}}$	1.4	1.3	1.4

In table IV the above results are compared with similar results from wrought products. Based on results at 10^5, 2×10^6, and 10^7 cycles, the average fatigue strength reduction factors for 14S-T6, 17S-T4, 27S-T6, and 53S-T6 are 2.4, 2.5 to 3.0, 2.2, and 1.8, respectively, compared with 1.4 for cast 355-T6 alloy. It appears, therefore, that the strength-reducing effects of an open hole in a plate are not so severe in a casting as in wrought material. On the other hand, the fatigue strengths of 14S-T6, 17S-T4, 27S-T6, and 53S-T6 with open holes are greater than that of 355-T6.

The results of tests on types 2 and 2A, 3 and 3A, and 5 and 6 are presented in figures 7(c), 7(d), and 7(e), respectively, in which the data points and average curves for the various specimens are superimposed on the scatter bands. In view of the inherent scatter of fatigue results found in these test data there appears to be no significant difference between any of the resulting curves.

The results of these fatigue tests are summarized in table V. Based on the average curves for each type of specimen, the results, as tabulated, indicate that the plain-type specimen has the highest fatigue strength and the type 1 specimen has the lowest fatigue strength of all types tested. Included in this table are fatigue strength reduction factors for each type of specimen based on the fatigue strengths of the plain-type specimen as unity; however, there is no apparent trend to these fatigue strength reduction factors.

The results of tests on plain-type specimens with as-cast surfaces from the previous investigation are plotted with the scatter bands of the present investigation in figure 8. This plot shows that a narrower scatter band was obtained in the previous investigation than in this investigation. Referring to figures 7(b), 7(e), and 8, it is evident that the scatter of results for the plain-type specimens of the present investigation exceeds the scatter for the previous investigation and that the fatigue strengths of the type 1 and type 5 specimens are in general lower than the results of the previous investigation, at least within the range of cycles covered therein.

Photographs of typical fatigue fractures are shown in figures 9, 10, and 11 while less typical failures are illustrated in figures 12 through 17. The paths of the fractures shown in figures 9, 10, and 11 are quite similar to those shown in figure 6 for the static specimens. It should be noticed that the fractures in the specimens with a reinforced hole passed near the edge of the boss and not through the hole. Just how much reinforcement is required to accomplish this was not determined by these tests. The fracture of the specimen with the unreinforced hole passed through the hole, as would be expected.

SUMMARY OF RESULTS

From the foregoing data and discussion of the static and fatigue tests on 355-T6 sand-cast plate-type aluminum-alloy specimens incorporating holes, bosses, and ribs, the following statements seem justified:

1. The mechanical properties of the castings tested conform to Federal Specification QQ-A-601, Class 10, and are in general agreement with published typical values.

2. In the static tests the tensile strength of the plain plate-type specimen agreed within 3 percent with the strength of separately cast test bars.

3. In terms of the average stress on the minimum net section of one specimen of each type, all the design details studied reduced the static strengths of the plate-type specimens. The reductions ranged from 4650 to 9000 psi or 13 to 26 percent.

4. Of the design details studied, the unreinforced hole was the most effective stress-raiser for fatigue lives from 10,000 to 25,000,000 cycles. Within this range of cycles the two curves, one for plain-type specimens and the other for specimens with the unreinforced hole, represent the two limits of fatigue strengths that might be expected with 355-T6 sand-cast aluminum with any or all design details studied.

5. The unreinforced hole in the sand-cast specimen was not so severe in reducing the fatigue strength as a similar hole in wrought 17S-T4, 27S-T6, 53S-T6, or 14S-T6 plate.

6. The fractures of both the static and fatigue specimens with a boss or rib were generally on cross sections close to the edge of the boss or rib. There were no fractures through the reinforced holes of types 2A and 3A.

Aluminum Research Laboratories
Aluminum Company of America
New Kensington, Pa., January 11, 1950

REFERENCES

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TABLE I

MECHANICAL PROPERTIES OF 355-T6 SAND-CAST MATERIAL[a]

[Standard separately cast test bars poured with the fatigue specimens]

Type of fatigue specimen	Heat or lot	Mechanical properties				Result from radiographic examination
		Tensile strength (psi)	Yield strength (0.2-percent offset) (psi)	Elongation in 2 in. (percent)	Brinell hardness number	
P	C1205	36,200	29,300	3.0	94	Superior
1	C1384	36,400	30,200	2.0	90	Uniformly sound
2 and 2A	C1704A	37,000	27,100	3.0	78	Generally sound
	C1704B	36,900	27,200	3.0	77	Generally sound
	C1704C	36,800	27,200	3.0	81	Generally sound
3 and 3A	C1582B	36,500	25,400	3.5	86	Generally sound
	C1582C	36,200	24,500	3.5	88	Generally sound
	C1582D	36,000	25,300	3.5	80	Generally sound
	C1582A	36,600	24,900	3.0	86	Generally sound
	C1582X	[b]33,200	[b]25,000	[b]2.5	[b]81	Generally sound
5	C1962B	35,200	25,800	3.0	81	Generally sound
	C2334	34,800	25,300	2.5	82	Generally sound
6	C2771	33,600	23,100	4.0	75	Generally sound
	C2779	34,700	23,200	4.0	81	Generally sound
Av.		35,720	25,960	3.11	82.9	

[a]Nominal composition: Copper, 1.3 percent; magnesium, 0.5 percent; silicon, 5.0 percent; aluminum, balance.
[b]Not poured at same time as plate-type specimens.

TABLE II

RESULTS OF STATIC TESTS ON SAND-CAST PLATE-TYPE SPECIMENS OF 355-T6 ALUMINUM ALLOY

Specimen type	Description	Plate-type specimen		Separately cast test bar (1)			
		Ultimate load (lb)	Tensile strength (psi) (2)	Tensile strength (psi)	Yield strength (0.2-percent offset) (psi)	Elongation in 2 in. (percent)	Stress-concentration factor (3)
P	Plain	62,000	35,200	36,200	29,300	3.0	1.03
1	Unreinforced hole	45,300	29,100	36,400	30,200	2.0	1.25
2	Boss with large fillet	59,750	29,000	36,900	27,200	3.0	1.27
2A	Same as type 2 with hole in boss	59,500	28,700	36,900	27,200	3.0	1.29
3	Boss with small fillet	59,200	30,000	36,300	25,000	3.4	1.21
3A	Same as type 3 with hole in boss	60,000	30,550	36,300	25,000	3.4	1.19
5	Transverse rib	60,700	27,600	35,000	25,500	2.8	1.27
6	Longitudinal rib	60,700	26,200	34,100	23,200	4.0	1.30

[1]Averages from table I.

[2]Based on net area of rectangular cross section; for types 2 to 6 inclusive, section taken at edge of boss or rib.

[3]Stress-concentration factor equals ratio of tensile strength of separately cast test bars to that of the plate-type specimen.

TABLE III

RESULTS OF FATIGUE TESTS OF 355-T6 SAND-CAST SPECIMENS

Specimen	Type	Range of tensile stress (psi)	Number of cycles to failure	Location of failure
C-1205-H	Plain	35,200	Static	Through center
C-1205-E	Plain	0 to 18,300	143,300	Through center
C-1205-A	Plain	0 to 14,890	137,700	3/4 in. from center
C-1205-B	Plain	0 to 9,850	1,749,100	1 in. from center
C-1205-D	Plain	0 to 8,960	677,300	7/8 in. from center
C-1205-F	Plain	0 to 7,310	21,059,000	No failure; removed
C-1384-A	1	29,100	Static	Through center
C-1384-B	1	0 to 20,000	8,500	Through center
C-1384-F	1	0 to 14,900	54,600	Through center
C-1384-H	1	0 to 12,400	191,400	Through center
C-1384-G	1	0 to 10,360	405,400	Through center; irregular
C-1384-C	1	0 to 8,300	1,038,500	Through center
C-1384-D	1	0 to 5,980	4,045,600	Through center
C-1384-E	1	0 to 5,010	71,537,600	No failure; removed
C-1704-C-2	2	29,000	Static	Above boss at minimum section
C-1704-C-5	2	[a]0 to 27,250	[b]99	Keyway
C-1704-A-5	2	0 to 17,050	[b]30,800	Fixture failed; specimen removed
C-1704-A-4	2	0 to 12,700	277,900	Above boss at minimum section
C-1704-C-4	2	0 to 9,960	815,800	Above boss; irregular
C-1704-A-3	2	0 to 8,570	825,000	Above boss at minimum section
C-1704-B-6	2	0 to 8,150	2,061,700	Below boss at minimum section
C-1704-C-1	2	0 to 6,960	26,305,300	No failure; removed
C-1704-B-8	2A	28,700	Static	Below boss at minimum section
C-1704-B-7	2A	[a]0 to 27,200	[b]71	Keyway
C-1704-C-3	2A	0 to 15,310	230,500	Top of reduced section; irregular
C-1704-B-4	2A	0 to 11,460	499,600	Above boss at minimum section
C-1704-A-1	2A	0 to 7,970	2,293,500	Below boss at minimum section
C-1704-A-2	2A	0 to 6,970	4,462,900	Below boss at minimum section
C-1704-A-8	2A	0 to 6,180	15,416,000	Above boss; irregular
C-1704-A-6	2A	0 to 5,740	15,137,400	Above boss at minimum section
C-1582-B-6	3	30,000	Static	Right below boss
C-1582-X-2	3	[a]0 to 29,900	[b]72	Keyway
C-1582-C-6	3	[a]0 to 25,900	1,052	Right below boss
C-1582-C-3	3	0 to 18,750	17,200	Right below boss
C-1582-D-2	3	0 to 14,700	136,900	Right below boss
C-1582-D-8	3	0 to 9,840	533,500	Right above boss
C-1582-C-5	3	0 to 7,470	2,638,600	Right above boss
C-1582-D-5	3	0 to 6,700	63,814,900	No failure; removed
C-1582-X-1	3A	30,550	Static	Right above boss
C-1582-B-2	3A	[a]0 to 28,800	[b]61	Keyway
C-1582-B-5	3A	0 to 17,780	88,100	Top of reduced section; irregular
C-1582-B-8	3A	0 to 15,200	224,200	$1\frac{3}{4}$ in. above boss; irregular
C-1582-C-2	3A	0 to 14,900	252,400	Right below boss
C-1582-B-3	3A	0 to 12,000	316,000	Right above boss
C-1582-B-4	3A	0 to 7,960	1,774,100	At edge in line below boss
C-1582-B-7	3A	0 to 6,050	134,627,600	No failure; removed
C-2334-7	5	27,600	Static	1/2 in. below rib
C-2334-2	5	0 to 16,750	133,000	$2\frac{1}{4}$ in. above rib; irregular
C-2334-3	5	0 to 12,600	476,400	Right below rib
C-2334-4	5	0 to 8,950	3,174,400	Right below rib
C-2334-1	5	0 to 7,840	882,600	Near edge; 1/2 in. above rib
C-2339-5	5	0 to 7,800	1,262,800	$1\frac{1}{4}$ in. below rib
C-1962-B-1	5	0 to 6,780	2,333,100	Top of reduced section
C-2334-6	5	0 to 6,480	4,665,900	$1\frac{1}{4}$ in. below rib; irregular
C-2334-8	5	0 to 5,930	95,503,200	No failure; removed
C-2779-B-1	6	26,200	Static	Right below rib
C-2779-B-4	6	[a]0 to 26,000	[b]2,100	No failure; removed
C-2779-B-3	6	0 to 15,200	179,600	Right above rib
C-2771-1	6	0 to 11,900	536,600	Right below rib
C-2779-B-2	6	0 to 9,220	1,922,200	At edge, right above rib; irregular
C-2771-5	6	0 to 7,700	4,083,000	Right above rib
C-2771-7	6	0 to 6,870	68,329,700	No failure; removed

[a]Tested in static testing machine.
[b]No visible failure in test section.

TABLE IV

COMPARISON OF FATIGUE STRENGTHS OF PLATE-TYPE SPECIMENS OF WROUGHT AND CAST MATERIALS WITH AND WITHOUT OPEN HOLE, BASED ON AVERAGE CURVES

$$\left[\text{Stress ratio} = \frac{\text{Minimum stress}}{\text{Maximum stress}} = 0\right]$$

Plate material	Type (a)	Tensile stress at failure (psi) at -			Description of specimen
		10^5 cycles	2×10^6 cycles	10^7 cycles	
[b]14S-T6	OX	46,700	32,300	27,600	Plain plate
[b]14S-T6	GX	18,700	12,900	11,800	41/64-in.-diam. hole
[c]17S-T4	OX	[d]43,200	32,400	31,400	Plain plate
[c]17S-T4	O	33,800	28,000	26,500	Plain plate
[c]17S-T4	G and GX	17,600	9,900	9,800	21/32-in.-diam. hole
[b]27S-T6	O	33,000	22,800	----------	Plain plate
[b]27S-T6	G and GX	15,200	11,000	10,500	21/32-in.-diam. hole
[b]53S-T6	O	27,200	23,000	----------	Plain plate
[b]53S-T6	G and GX	16,500	10,700	10,000	21/32-in.-diam. hole
355-T6	Plain	18,500	8,900	7,650	Plain plate
355-T6	1	13,650	6,900	5,600	1-in.-diam. hole; machined rim

Fatigue strength reduction factors (e)

Cycles	Plate material					
	14S-T6	17S-T4 (f)	17S-T4 (g)	27S-T6	53S-T6	355-T6
10^5	2.5	2.5	1.9	2.2	1.6	1.4
2×10^6	2.5	3.3	2.8	2.1	2.1	1.3
10^7	2.3	3.2	2.7	---	---	1.4
Av.	2.4	3.0	2.5	2.2	1.8	1.4

[a]Type O, solid plate, minimum section $4\frac{3}{4}$ by 1/4 in.;

Type OX, solid plate, minimum section $4\frac{3}{4}$ by 1/4 in., plate fulcra machined in specimen to reduce bending;

Type G, drilled hole, test section 2 by $7\frac{1}{2}$ by 1/4 in.;

Type GX, drilled hole, test section 9 by $7\frac{1}{2}$ by 1/4 in.

[b]Unpublished results.

[c]Results from reference 4 plus more recent test results.

[d]From extrapolated curve.

[e]Ratio of fatigue strengths of solid to drilled specimens.

[f]Based on fatigue strengths of type OX specimens.

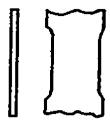
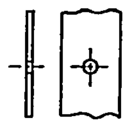
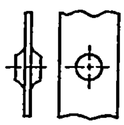
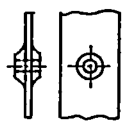
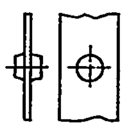
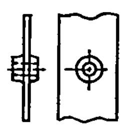
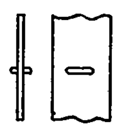
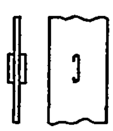
[g]Based on fatigue strengths of type O specimens.

TABLE V

SUMMARY OF TEST RESULTS BASED ON AVERAGE CURVES - EFFECT OF HOLES,

BOSSES, AND RIBS ON THE STRENGTH OF 355-T6 SAND CASTINGS

$$\left[\text{Stress ratio} = \frac{\text{Minimum stress}}{\text{Maximum stress}} = 0\right]$$

Specimen		Static test results		Tensile fatigue strength (psi) at -		
		Ultimate load (lb)	Ultimate strength (psi) (a)	10^5 cycles	2×10^6 cycles	10^7 cycles
Plain		62,000	35,200	18,500	8,900	7,650
Type 1		45,300	[b]29,100(1.21)	13,650(1.35)	6,900(1.29)	5,600(1.36)
Type 2		59,750	29,000(1.21)	15,850(1.17)	8,300(1.07)	7,050(1.08)
Type 2A		59,500	28,700(1.23)	16,050(1.15)	8,250(1.08)	6,200(1.23)
Type 3		59,200	30,000(1.17)	14,300(1.29)	7,950(1.12)	7,000(1.09)
Type 3A		54,100	30,550(1.15)	17,300(1.07)	7,950(1.12)	6,600(1.16)
Type 5		60,700	27,600(1.27)	18,450(1.00)	7,000(1.27)	6,100(1.25)
Type 6		60,700	26,200(1.34)	17,750(1.04)	8,800(1.01)	7,200(1.06)

[a]Based on minimum net area.

[b]Figures in parenthesis represent stress-concentration or fatigue strength reduction factors based on strengths of plain-type specimen.

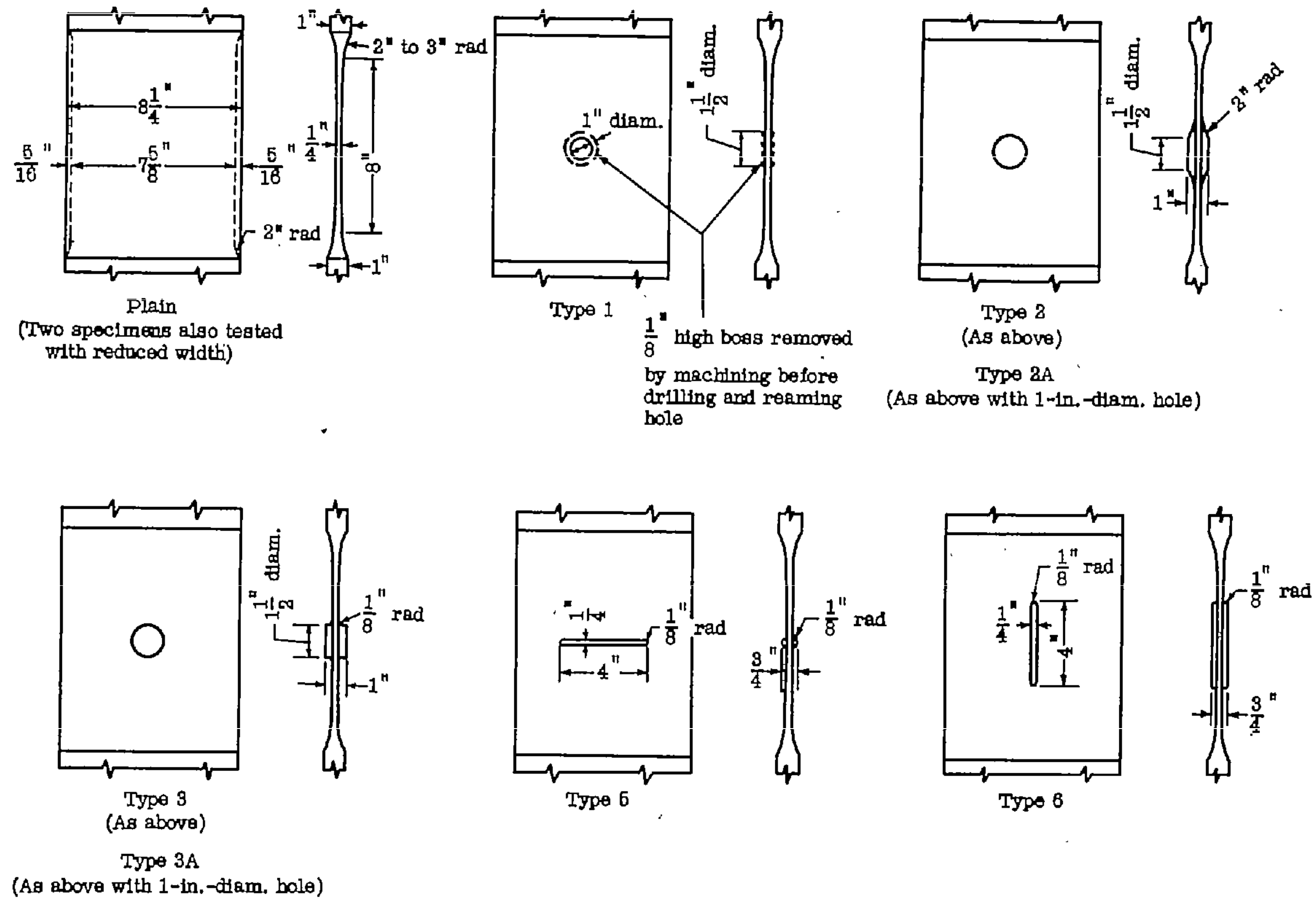


Figure 1.- Plate-type specimens produced by sand-casting for study of effects of design details on static and fatigue strength. Various types obtained by altering the basic pattern. 355-T6 aluminum alloy.

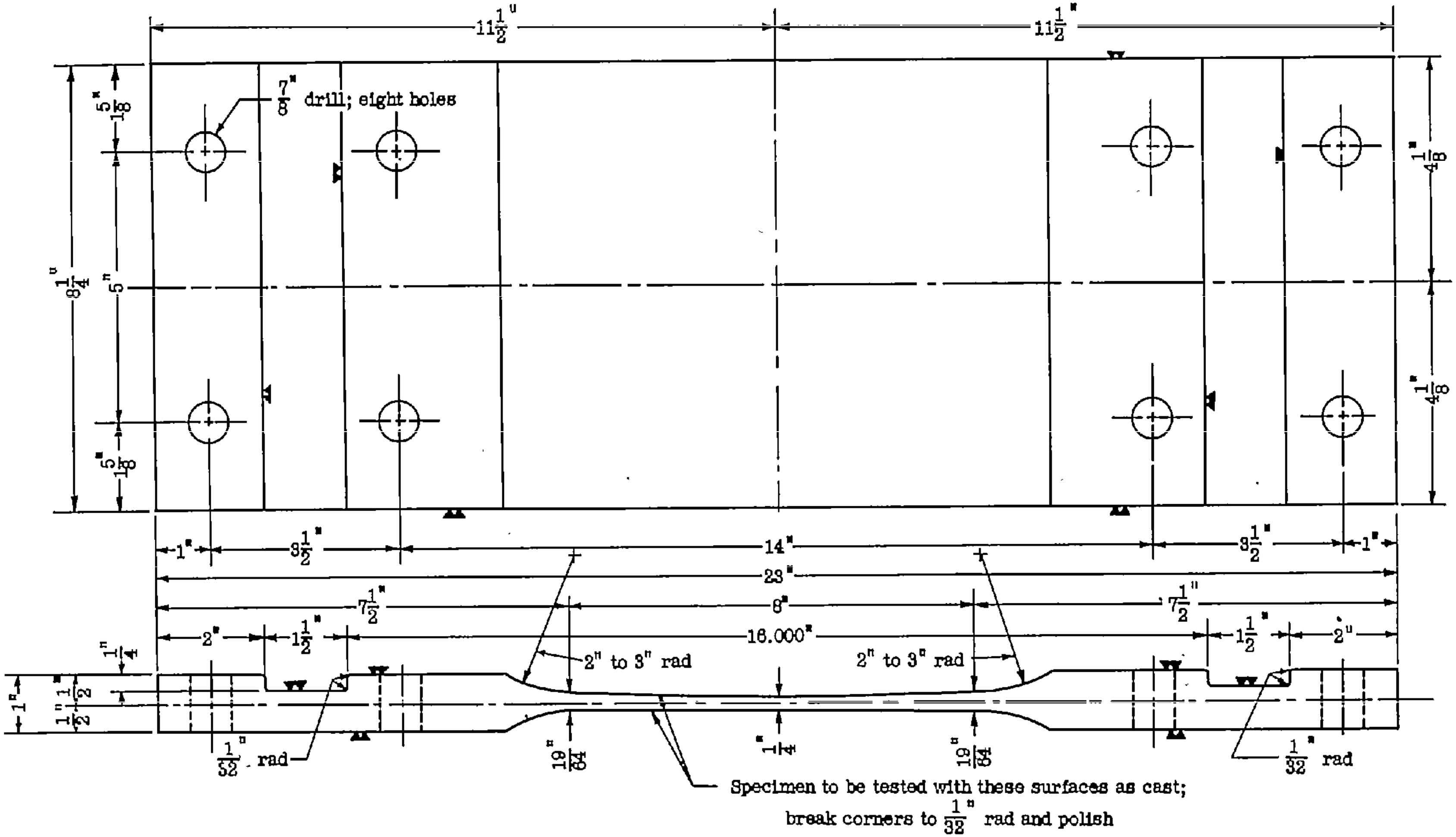


Figure 2.- Cast fatigue specimen having rectangular cross section.

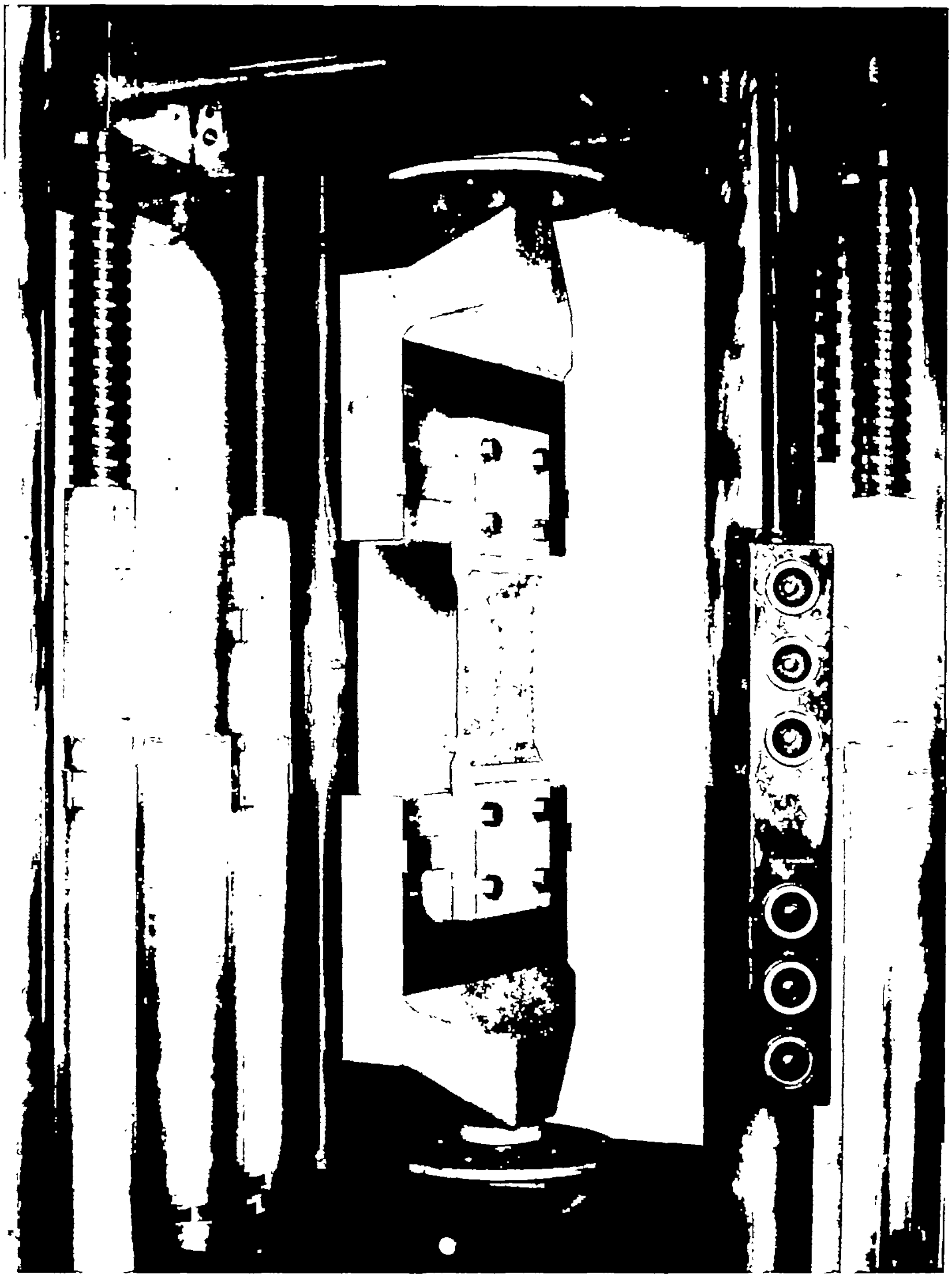


Figure 3.- Static test fixtures designed by Mr. R. L. Templin. Fixtures are equipped with spherically seated tension bolts.

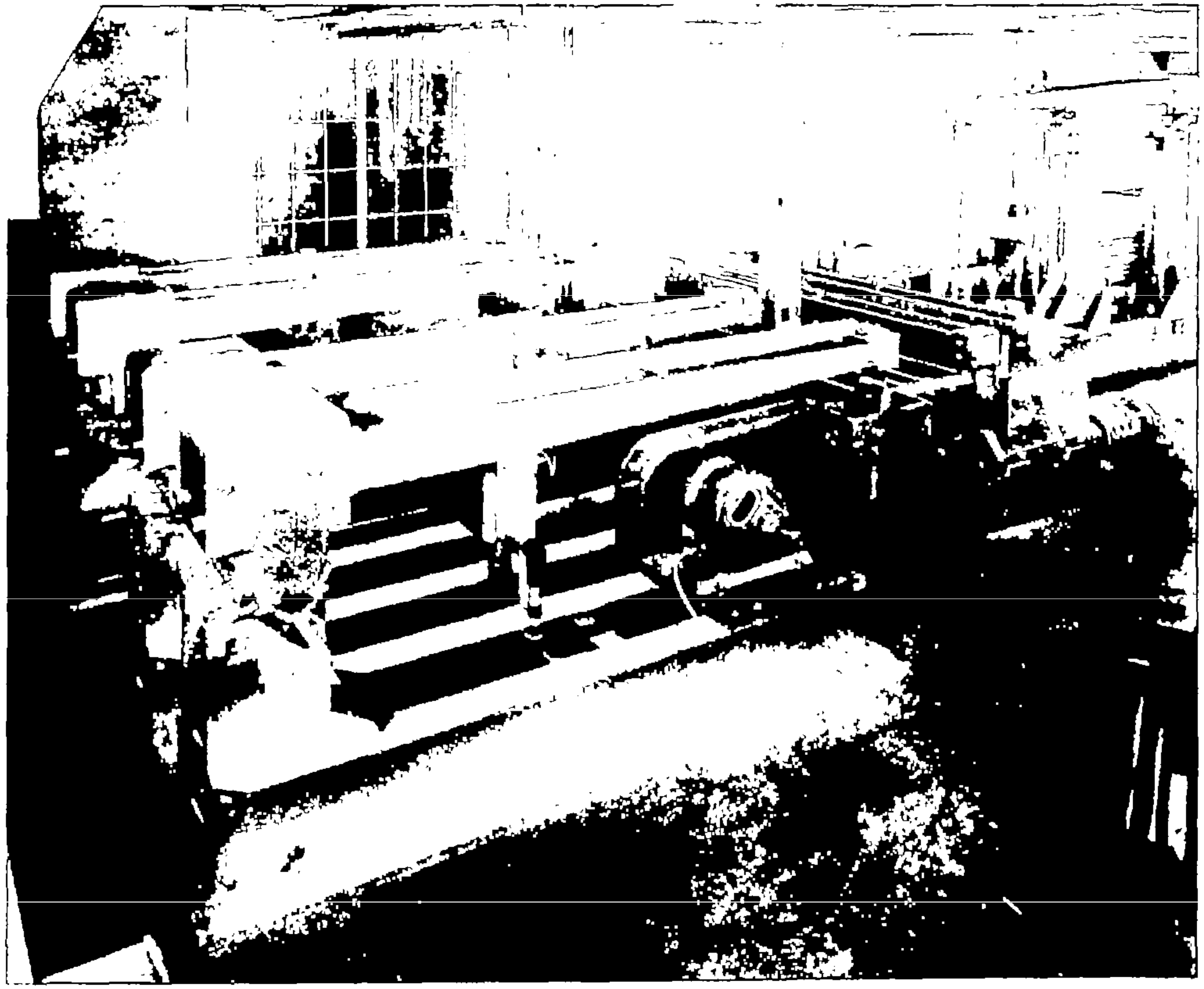


Figure 4.- Direct-stress fatigue machine for testing structural units.

Figure 5.- Adapters, designed by Mr. R. L. Templin, including plate fulcra at each end which are alined with longitudinal axis of specimen.

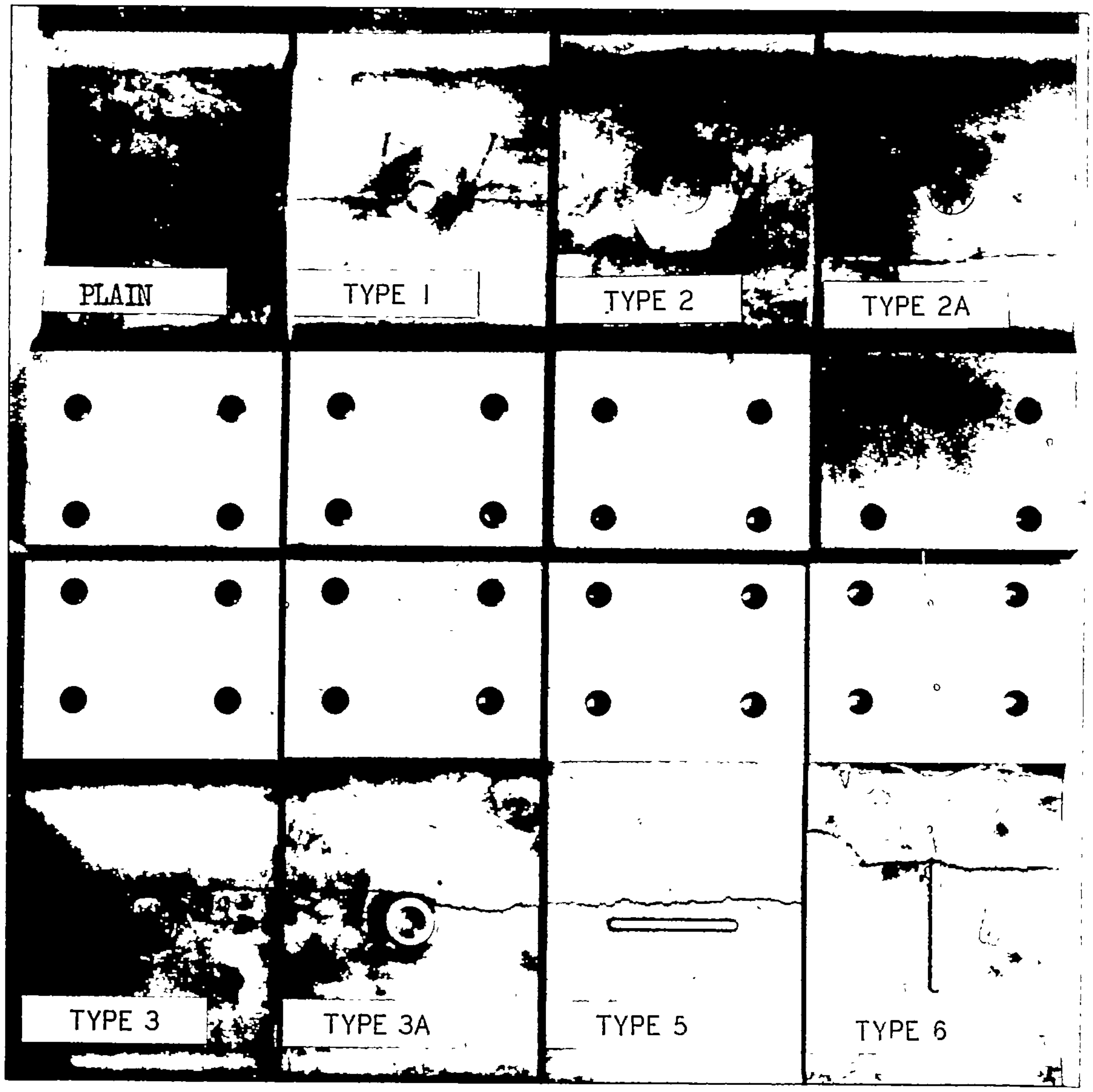
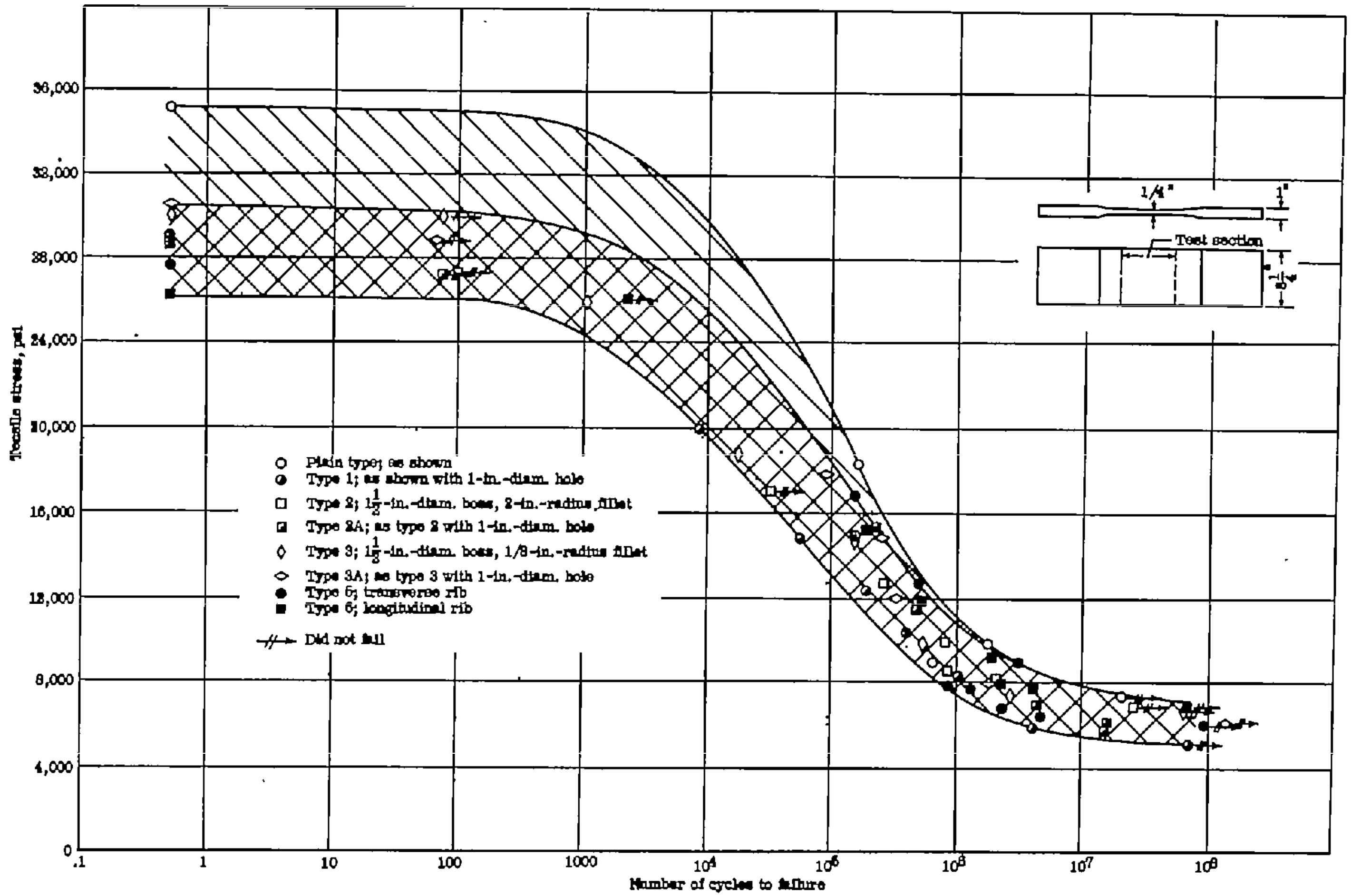


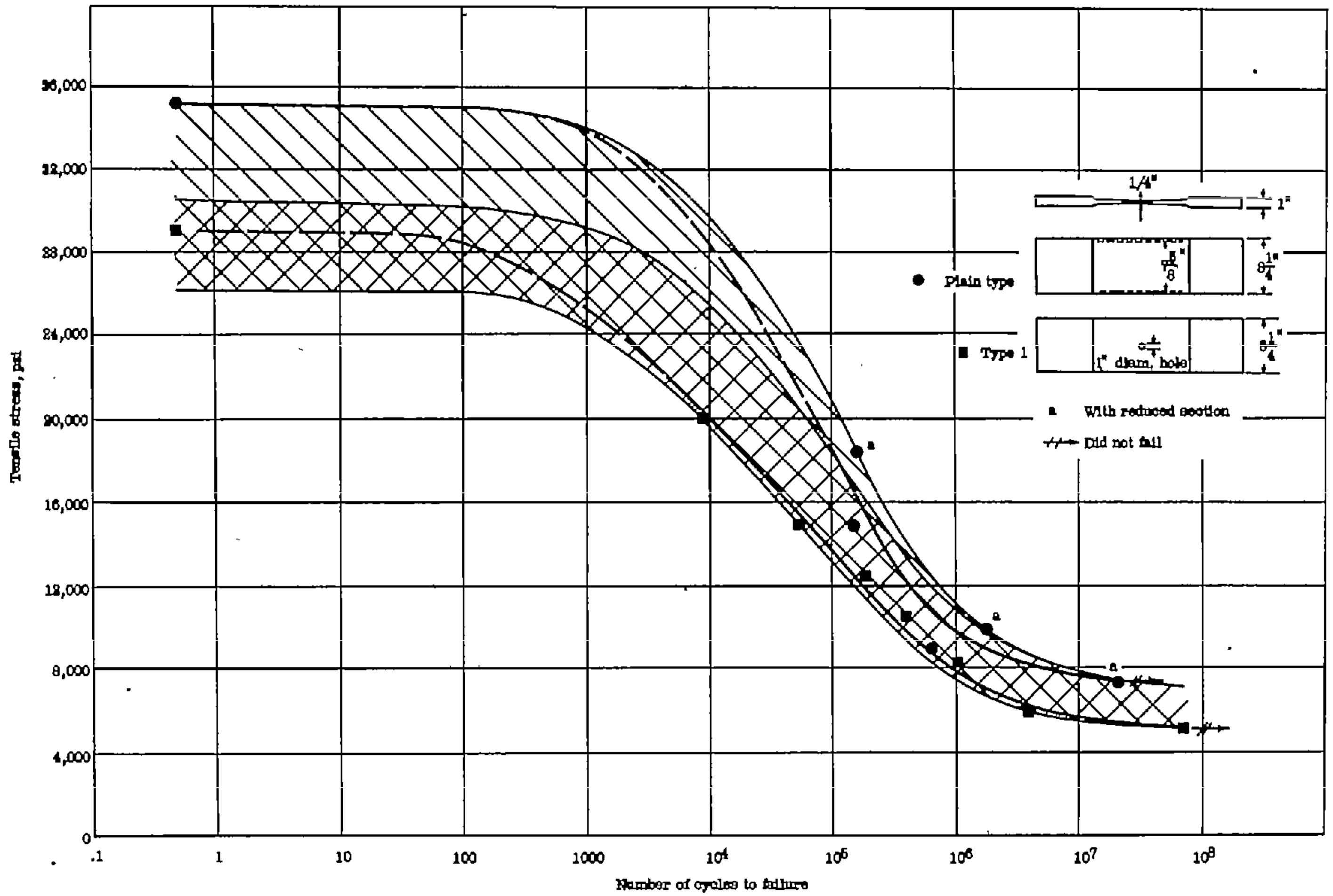
Figure 6.- Fractures in static specimens. Plate-type 355-T6 sand castings.



(a) All tests.

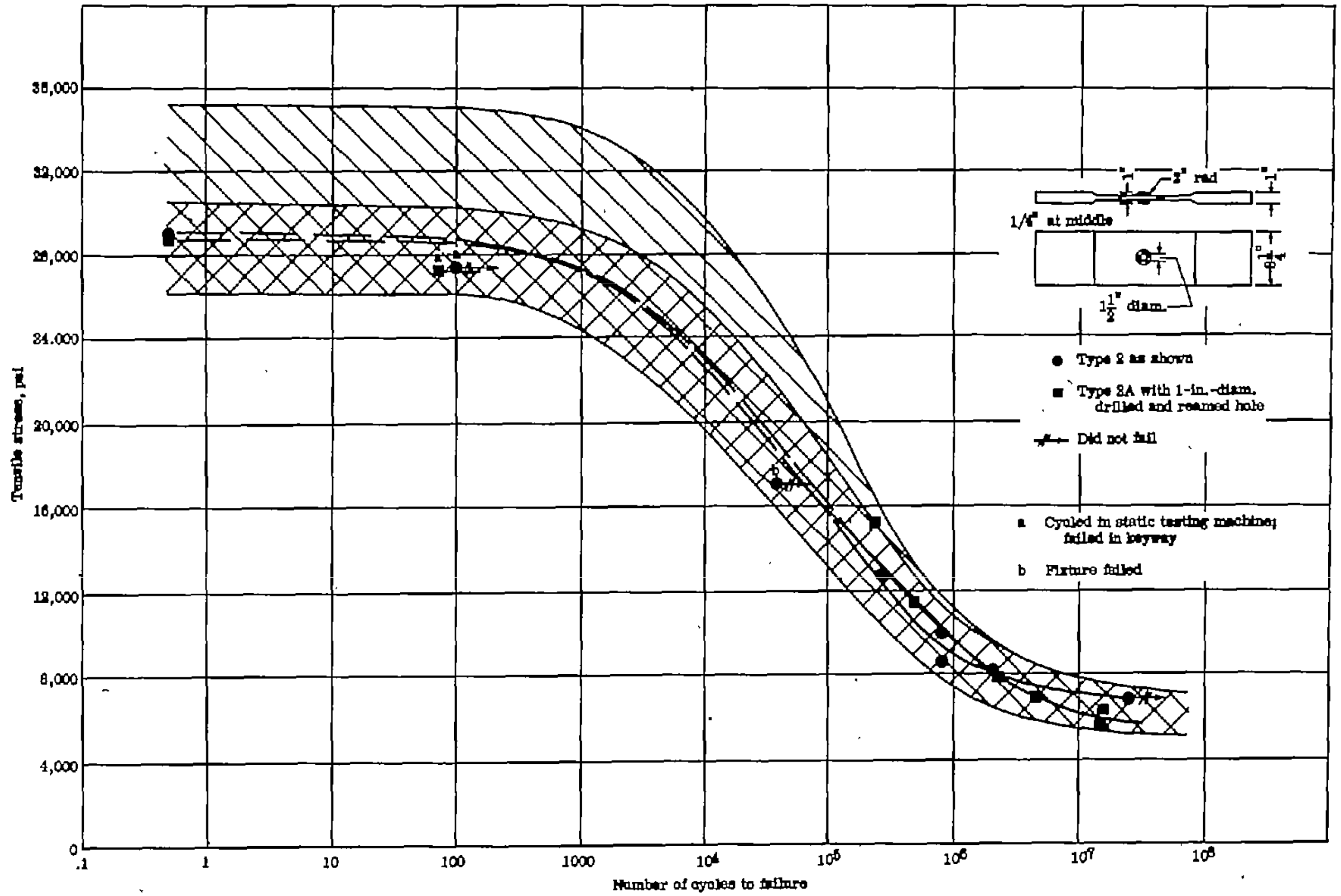
Figure 7.- Results of fatigue tests on 355-T6 sand-cast specimens.

$$\text{Stress ratio} = \frac{\text{Minimum stress}}{\text{Maximum stress}} = 0.$$



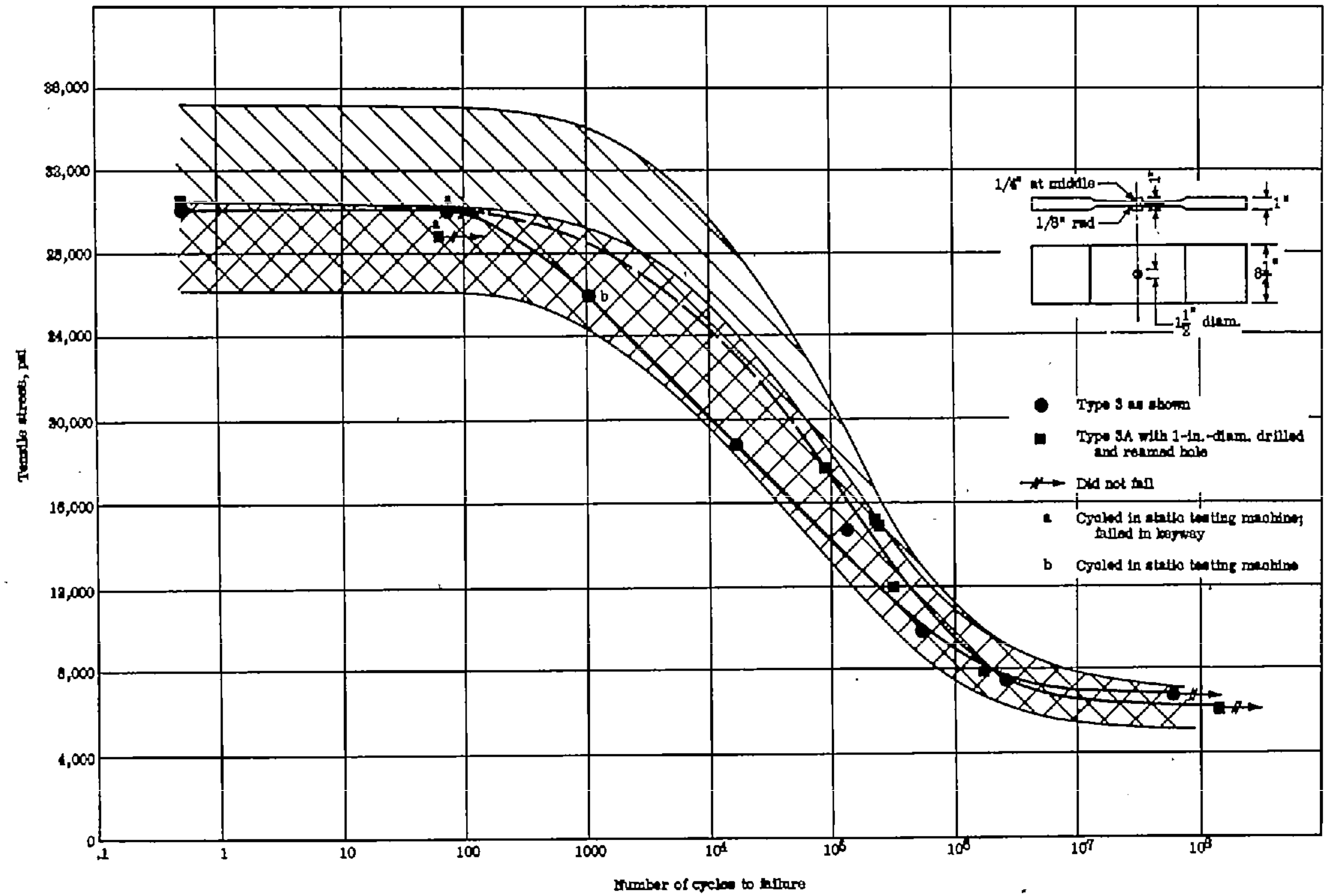
(b) Tests on plain-type and type 1 specimens.

Figure 7.- Continued.



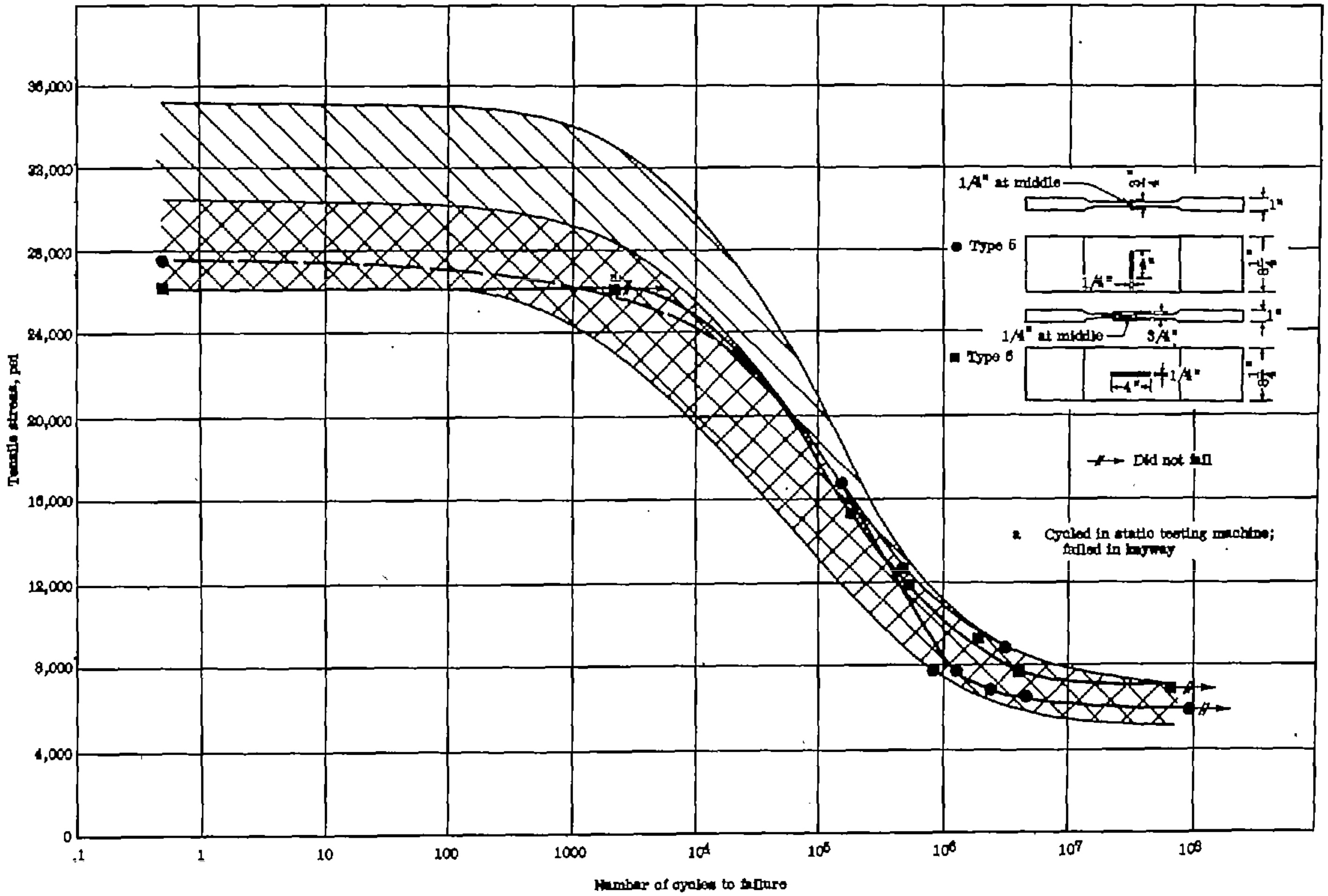
(c) Tests on type 2 and type 2A specimens.

Figure 7.- Continued.



(d) Tests on type 3 and type 3A specimens.

Figure 7.- Continued.



(e) Tests on type 5 and type 6 specimens.

Figure 7.- Concluded.

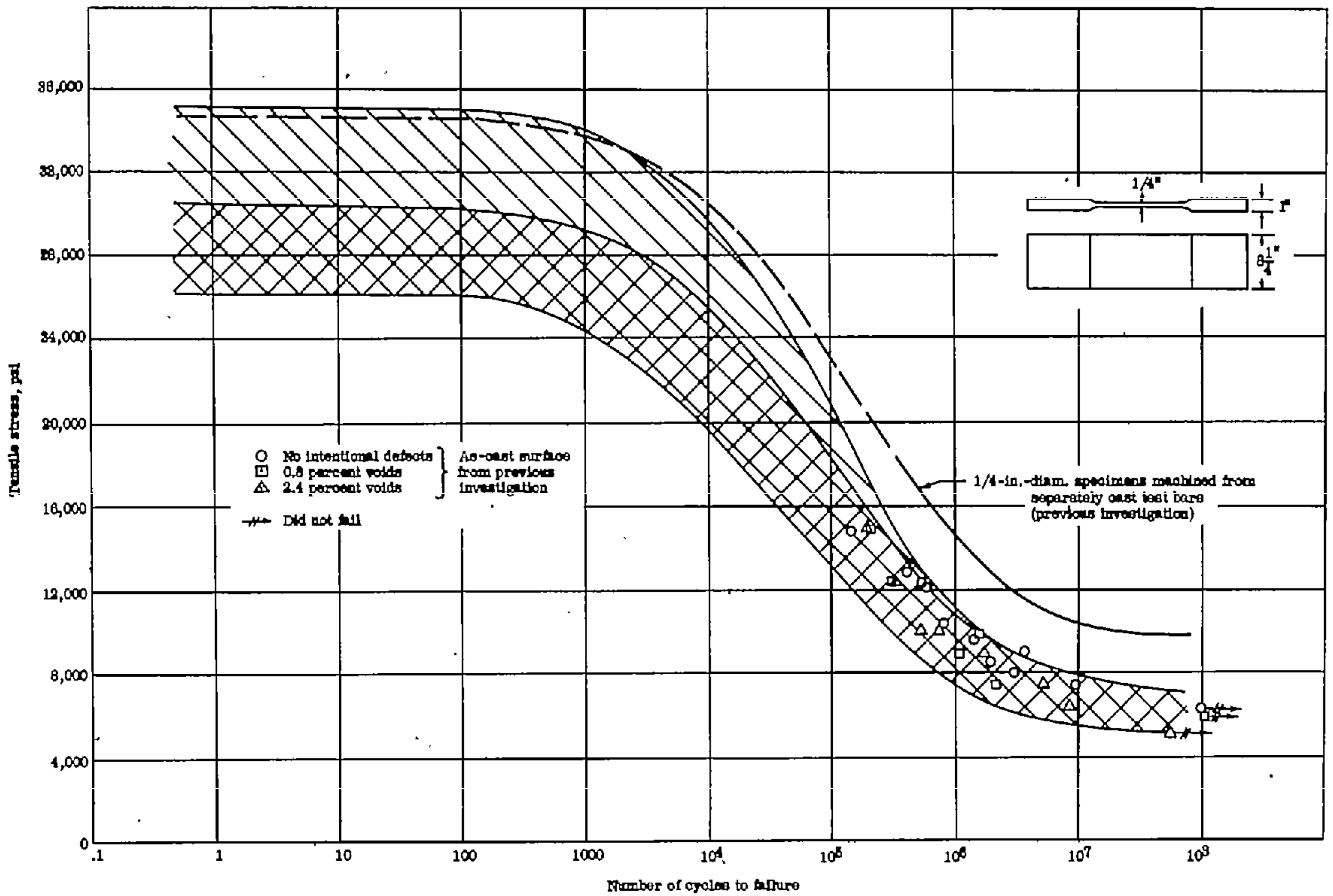


Figure 8.- Results of fatigue tests on 355-T6 sand-cast specimens. Plain-type specimens with as-cast surfaces from previous investigation included. Stress ratio = $\frac{\text{Minimum stress}}{\text{Maximum stress}}$ = 0.

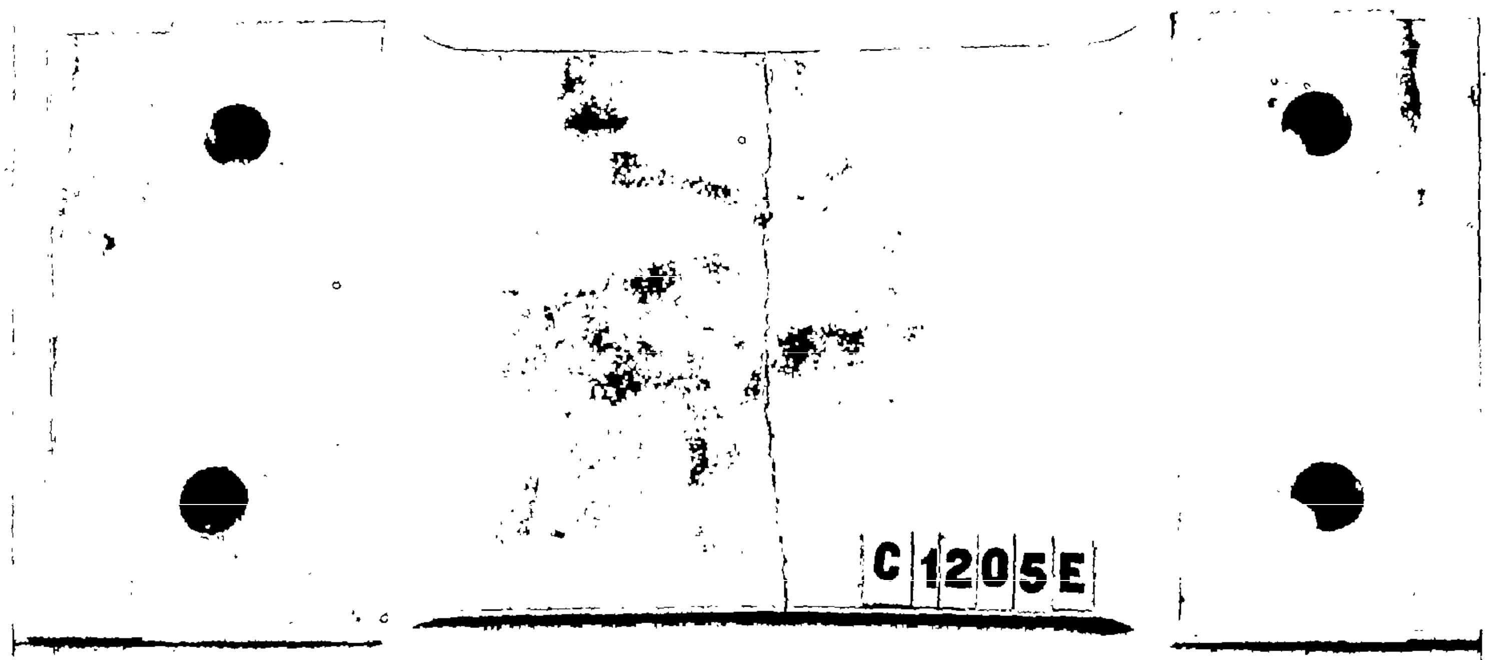


Figure 9.- Typical fatigue fracture in plain-type specimen.

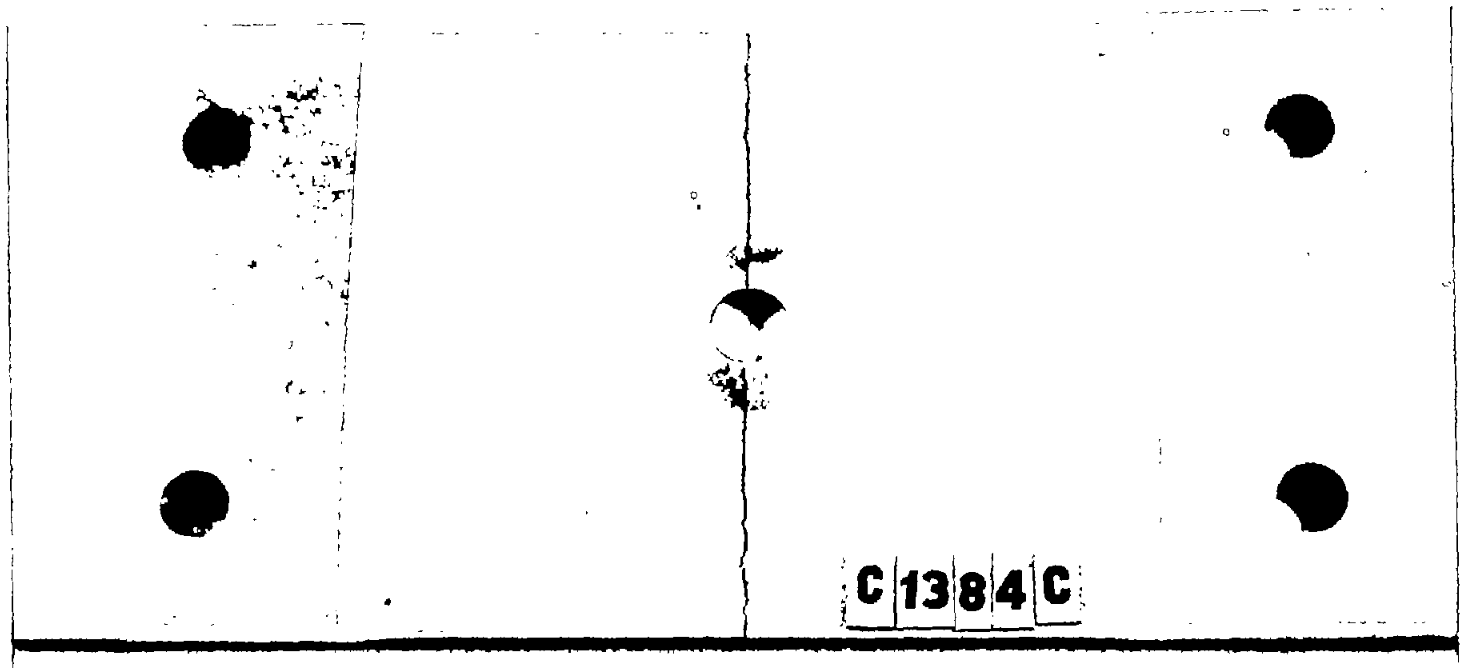


Figure 10.- Typical fatigue fracture in type 1 specimen.

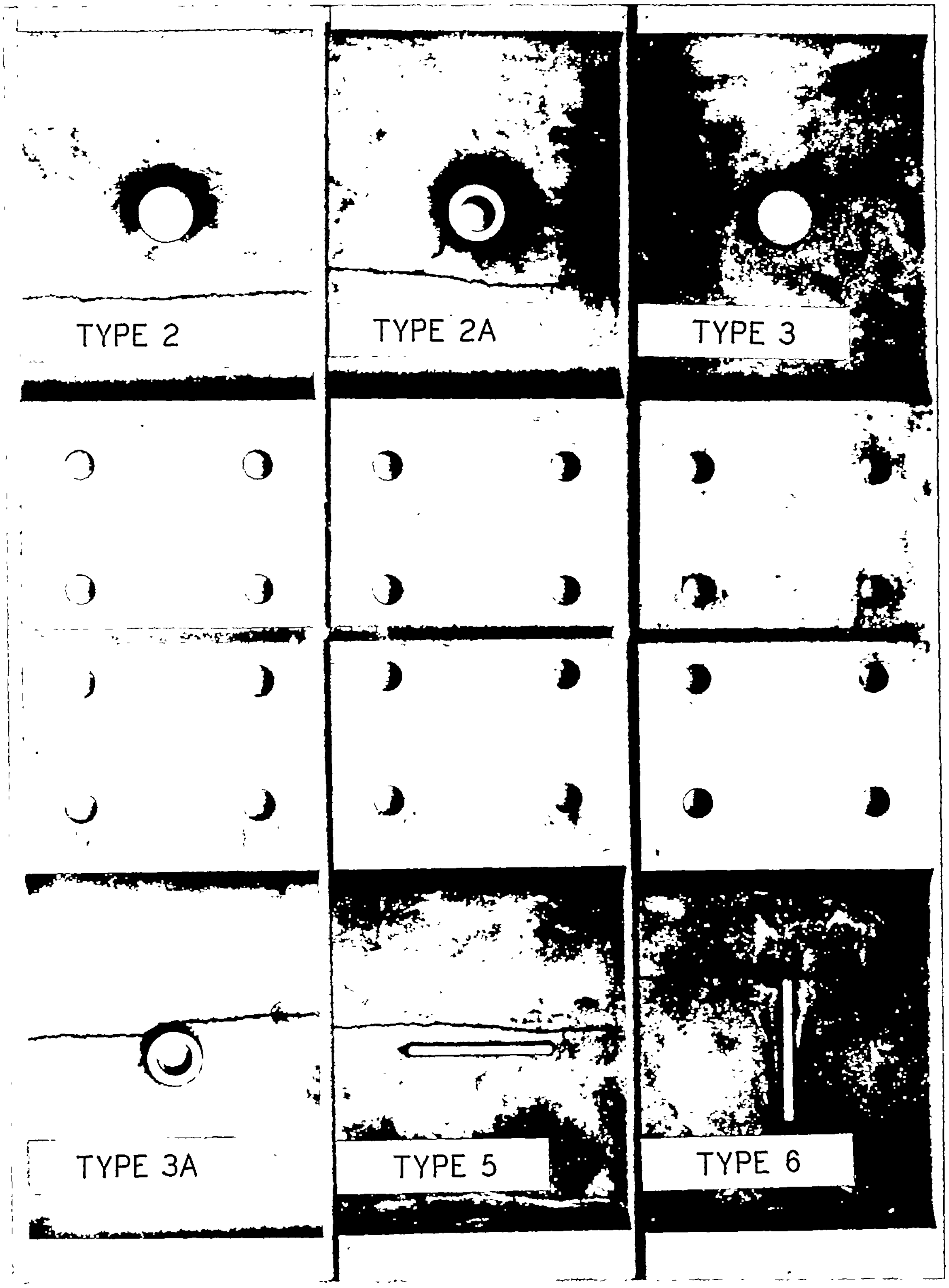


Figure 11.- Typical fracture in fatigue specimens. Plate-type 355-T6 sand castings with bosses and ribs.

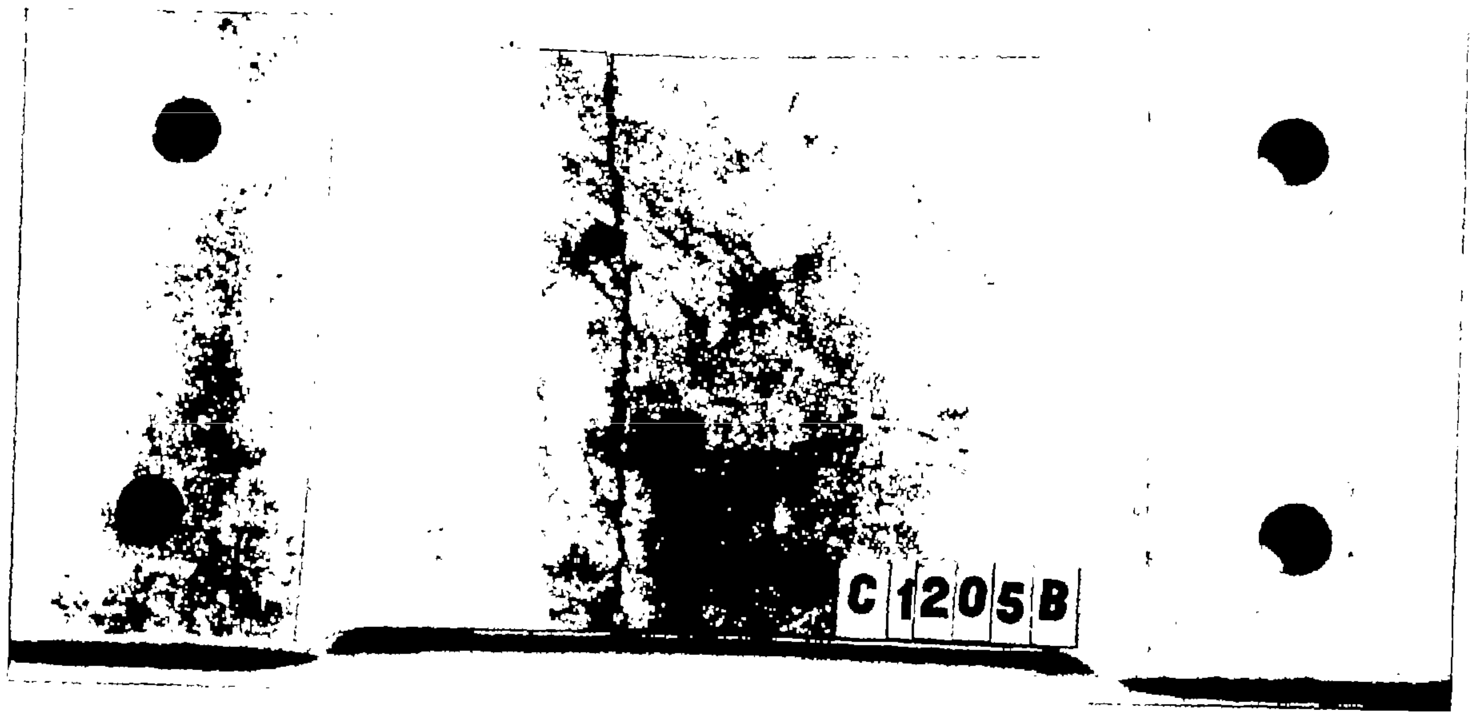


Figure 12.- Fracture in plain specimen 1 inch from minimum section.

Figure 13.- Failure in type 2A specimen near end of reduced section.

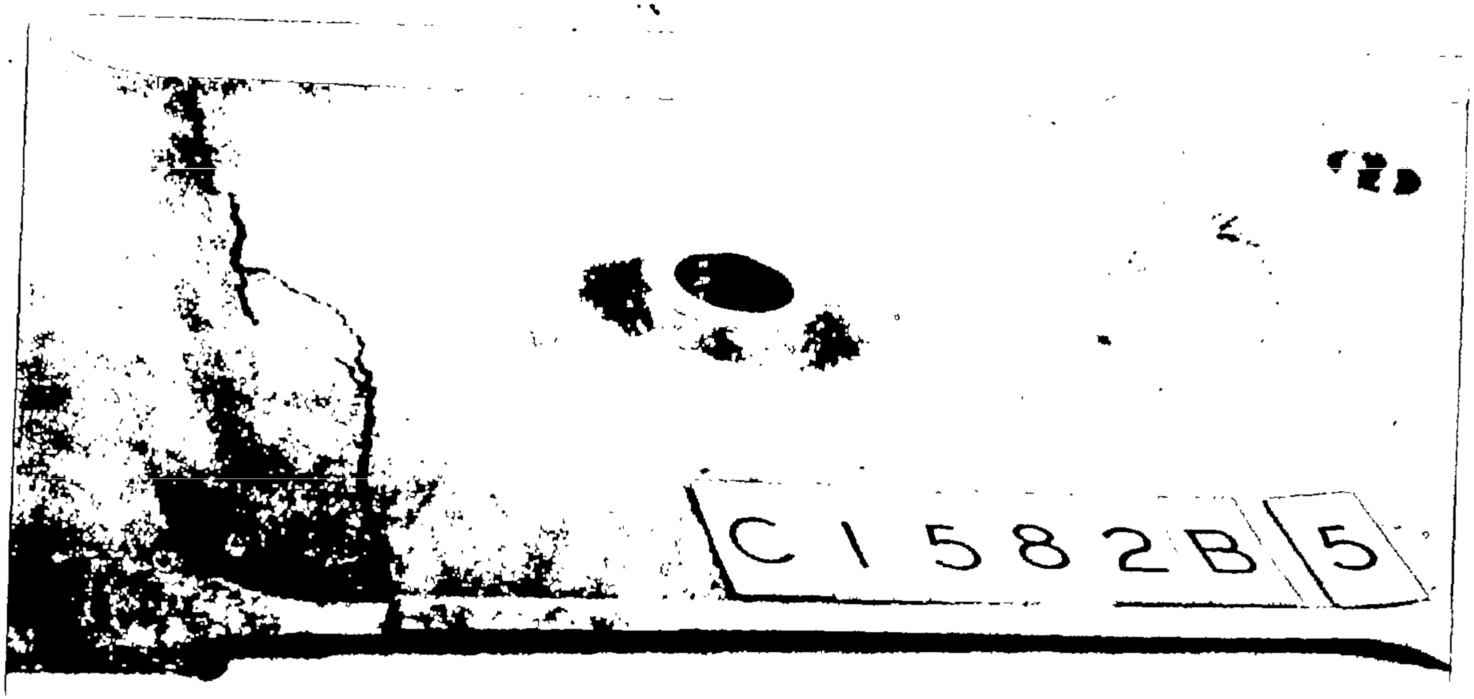


Figure 14.- Failure in type 3A specimen. Top of reduced section.

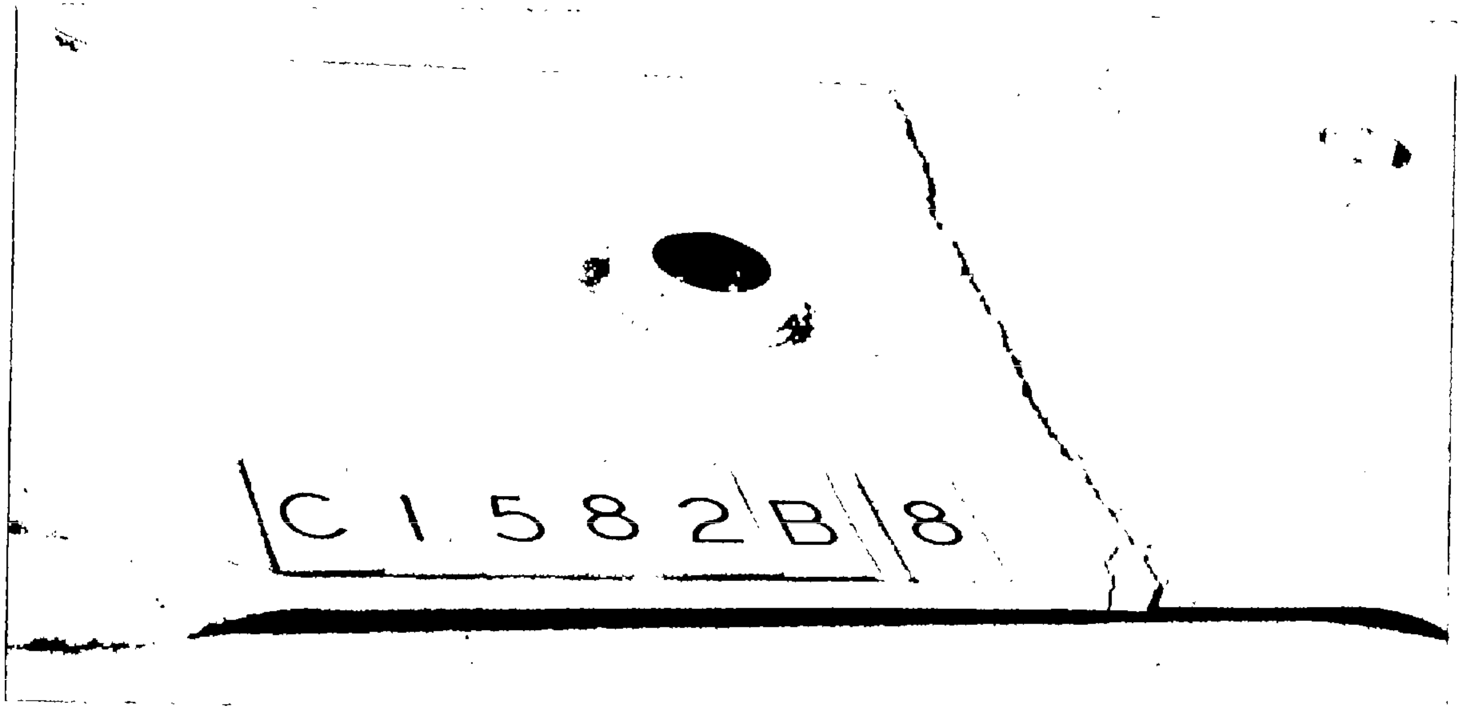


Figure 15.- Failure in type 3A specimen between edge of boss and end of reduced section.

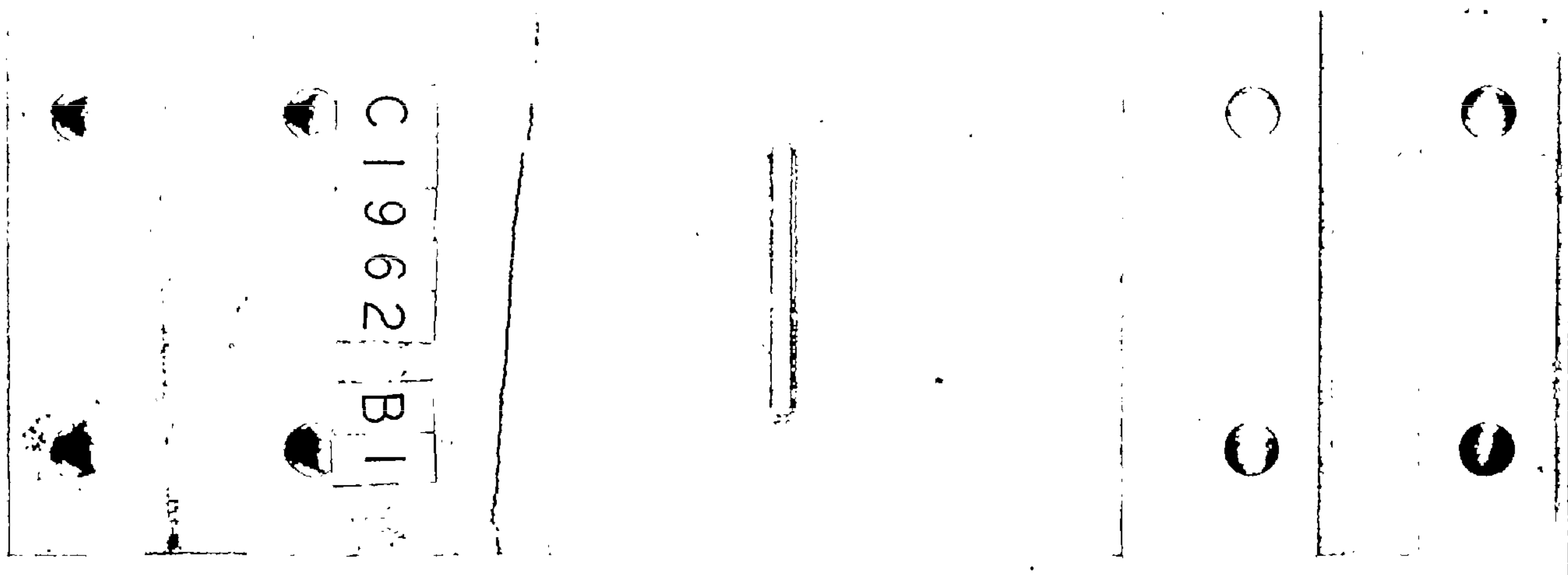


Figure 16.- Failure in type 5 specimen. Top of reduced section.

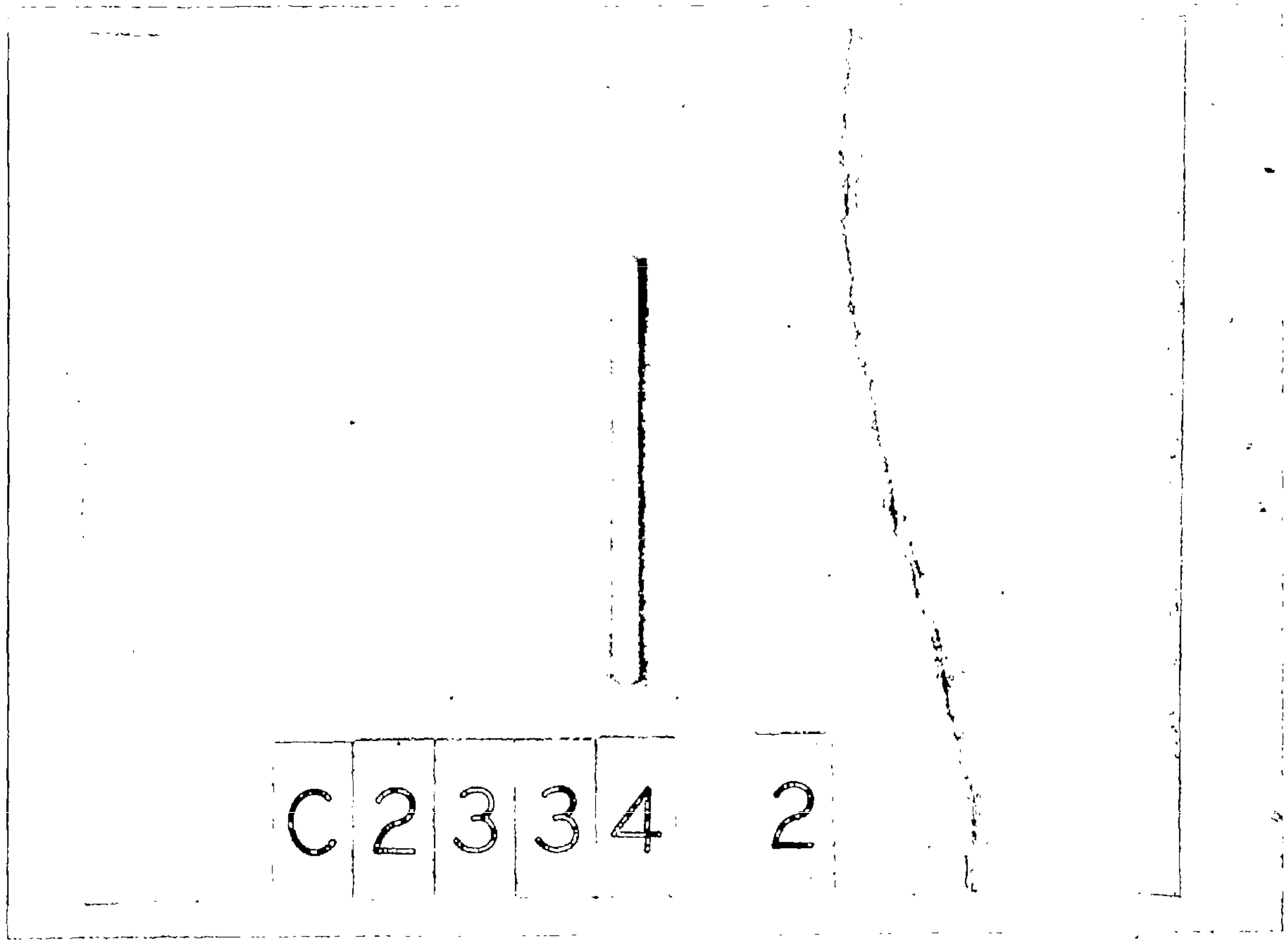


Figure 17.- Failure in type 5 specimen between rib and end of reduced section.

NACA-Langley - 7-13-51 - 1000